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**March 18, 2004**

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**APPLICATION NUMBER: 60/419,477**

**FILING DATE: October 18, 2002**

**RELATED PCT APPLICATION NUMBER: PCT/US03/33132**

**By Authority of the  
COMMISSIONER OF PATENTS AND TRADEMARKS**



*M. Sias*  
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Certifying Officer**

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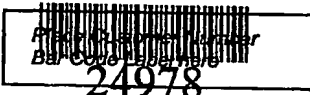
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## PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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| INVENTOR(S)  |  |                              |  |   |  |
|--|--|------------------------------|--|---|--|
| Given Name (first and middle [if any])   |  | Family Name or Surname       |  | Residence<br>(City and either State or Foreign Country)                             |  |
| Vitali<br>Mervyn L.<br>Phillip   |  | Nesterenko<br>Rudee<br>Mages |  | La Jolla, CA<br>La Jolla, CA<br>San Diego, CA                                       |  |
| <input checked="" type="checkbox"/> Additional inventors are being named on the <u>1</u> separately numbered sheets attached hereto                  |  |                              |  |   |  |
| TITLE OF THE INVENTION (280 characters max)  |  |                              |  |   |  |
| METHOD FOR STRENGTH AND YIELD IMPROVEMENT IN WAFER BONDING   |  |                              |  |   |  |
| Direct all correspondence to: CORRESPONDENCE ADDRESS   |  |                              |  |   |  |
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| ENCLOSED APPLICATION PARTS (check all that apply)  |  |                              |  |   |  |
| <input checked="" type="checkbox"/> Specification  |  | Number of Pages              |  | 4   |  |
| <input type="checkbox"/> Drawing(s)  |  | Number of Sheets             |  |   |  |
| <input type="checkbox"/> Application Data Sheet  |  | See 37 CFR 1.76              |  |   |  |
| <input type="checkbox"/> CD(s)   |  | Number                       |  |   |  |
| <input type="checkbox"/> Other (specify)   |  |                              |  |   |  |
| METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT   |  |                              |  |   |  |
| <input checked="" type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27.   |  |                              |  | FILING FEE AMOUNT (\$)  |  |
| <input checked="" type="checkbox"/> A check or money order is enclosed to cover the filing fees  |  |                              |  |   |  |
| <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: |  | 07-2069                      |  | \$80.00   |  |
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| The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.              |  |                              |  |   |  |
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Respectfully submitted,

SIGNATURE

TYPED or PRINTED NAME

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Date

10 18 02

REGISTRATION NO.  
(if appropriate)  
Docket Number:

35,132

0321.67046

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**PROVISIONAL APPLICATION COVER SHEET**  
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| Docket Number                          |                   | 0321.67046  | Type a plus sign (+)<br>inside this box → | + |
|--|-------------------|---|---|---|
| INVENTOR(S)/APPLICANT(S)               |                   |   |   |   |
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Patent Application

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This invention utilizes the preliminary weak bonding of semiconductor wafers with subsequent containerless application of gas isostatic pressure simultaneously with heat treatment at prescribed pressures, temperatures and times in order to improve bonding strength and the yield of strongly bonded wafers. The pressure is uniformly applied using a gas medium (Argon for example) in a Hot Isostatic Press (for example QIH-3). The pressure and temperature can be controlled separately so as to tailor the bonding process and residual level of stresses for optimal conditions. Preliminary weak bonding does not allow penetration of pressure transmitting media in the space between wafers and helps avoid the need for sealing the sample into vacuum tight container. HIPing without preliminary weak bonding at the same conditions did not result in wafer bonding.

The application of high pressures evenly over the large area of sample and maintaining pressure on the stage of cooling are unique capabilities of the proposed method which significantly improves the strength of the bond between the two (or more) wafers involved. Such treatment allows for materials with different thermal expansion coefficients to be joined despite stresses arising from the thermal mismatch. Furthermore the nature of the pressure application allows for uniform pressure to be placed on bonded samples with complex geometry or on multiple samples simultaneously without their macroscopic plastic deformation.

Hot Isostatic Pressing is traditionally used for large macroscale operations like densification of powders and castings, diffusion bonding of structural materials like bronze and steel, ceramic-metal bonding. The use of the gas-mediated pressure application to preliminary weakly bonded wafers of semiconducting materials for enhancement of a strong bonding with desirable optoelectronic properties without encapsulation is unique and has not been mentioned before in the scientific literature. Despite the fact that application of pressure is considered in general favorable for diffusion bonding, the use of HIPing as important technological step for the specific application to semiconductor devices was not experimentally proved before and can be considered as novel in itself. This is due to the fact that it is not apparent at all that the relatively low level of pressures (about 2 kbars or less) and temperatures (below 700 °C) applied during the reasonable time will facilitate diffusion bonding to the level desirable for industrial applications, while ensuring useful optoelectronic properties.

Bonding of wafers with different thermal expansion coefficients typically use uniaxial pressure (for example in a graphite/quartz reactor) to allow for bonding to occur. The existing method - a graphite/quartz fixture for successful wafer bonding does not specify a level of pressures - only reference to "enormous pressure" was made. Level of temperatures (520 °C - 830 °C) was specified in the prototype method as well as typical time period about 2 hours. The prototype method has a disadvantage due to the plastic deformation and bending of wafers which is generic drawback of practically any contact anvil-type pressure application. The existing processes require the mechanical application of pressure and are difficult to scale to large samples without inhomogeneous pressure application resulting. The proposed method based on HIPing of weakly bonded samples guarantees uniform pressure application by the use of gas pressure at any size of the samples, orientation or geometry and minimizes the plastic deformation of bonded wafers.

The ability to monitor the pressure application in the proposed method independently during the heating stage is also unique. Existing anvil type devices typically rely either on differential thermal expansion or on the tightening of a vise prior to heating in order to produce the desired pressures. As a result, the pressures exerted are linked to the temperature increase both of the sample and fixture. In our case, the pressure can be set independent of the sample temperature and can be kept constant not only during the heating run but most important on the stage of cooling also. The use of hot isostatic pressing provides a reproducible method of applying pressure independently of temperature which is not attainable using mechanical tightening of vises

or shimming of differential thermal expansion devices.

The conditions on pressure, temperature and time for achieving a desirable level of strong bonding of wafers do not logically follow from some known experimental results or from physical laws. It is also impossible to predict these conditions theoretically due to the lack of reliable theory which is able to describe pressure assisted bonding. The sequence of technological steps (especially weak bonding of wafers allowing HIPing without encapsulation) and time-temperature-pressure parameters of HIPing for given wafers must be found experimentally. A different cycles for different materials should be developed. At the same time successful demonstration of HIPing of weakly bonded wafers without encapsulation demonstrates that the process can be also successful for other materials due to the similarity of their mechanical and physical properties.

It should also be mentioned here that the proposed process allows the direct bonding of materials without the use of an intermediate layer. It also allows for such bonding without the use of Ultra-high Vacuum (UHV) chambers as required by some techniques described below. The gas pressure assisted process can be applied to less critical applications than those requiring direct bonding, but the focus here is on the most critical application since it presents difficulties not adequately addressed by other means.

Besides possibility to successfully replace method where pressure application is necessitated by thermal expansion mismatch issues, HIP assisted bonding has promise for the processing of other wafer bonded material systems. In such systems, pressure application has not been explored since satisfactory bonding can be achieved without the pressure application. However, the appearance of defects at the bonded interfaces may be prevented by the application of isostatic pressure since many such defects involve an increase in volume which would be less energetically favorable under high isostatic pressure. Additional advantages can be connected with decrease of temperature and time required to achieve a strong bonding due to pressure application.

Wafer bonding itself is a broad field with many different techniques. The first distinction between techniques is that of direct vs. indirect bonding. The first type of bonding involves the joining of two wafers without the use of any sort of layer in between them to facilitate strong bonding. This type of bonding is more difficult than techniques utilizing oxides or reactive interlayers, but it yields material with more flexible applicability. Few applications of this type of technique have succeeded at this time and methods allowing for such bonding will be revisited below.

The second type of bonding may involve the use of metallic interlayers or oxide layers, which strengthen the bond. These techniques do not allow for interface characteristics to be tailored for any use besides mechanical joining or perhaps contact formation, in the case of a conductive interlayer. Most low temperature bonding techniques involve the use of some sort of interlayer, most often an oxide formed from the materials. The recently advertised technique (Motorola) of creating GaAs-on-Si wafers yields wafers joined by such an interlayer.

Wafer bonding without the use of any interlayer is often termed wafer fusion in order to highlight the special nature of the bonded interface. Unlike the cases where interlayers are used, the fusion technique allows the bonded materials to be integrated into the active regions of the device for full utilization of the properties of both materials. The most difficult applications of wafer bonding are those where two materials having different thermal expansion coefficients are fused together. Such fusion normally requires high temperature treatments to ensure a covalent bond between the different materials.

The standard approach for overcoming this so-called thermal mismatch is to load the samples into some apparatus designed to press the wafers together during the heating process. Often this is done using a mechanical vise constructed of suitable materials for the temperatures and ambients to be used. The controllability of such devices relies heavily on the precise tightening of screws or bolts, or even the placing of a large weight on top of the samples or fixture. Another method for pressing the wafers together relies on the thermal expansion of the sample and parts of the pressure fixture to exert large forces pushing the wafers together during heating stage. For example, by placing the sample between two pieces of graphite and then placing the resulting group inside of a hole machined from a solid block of quartz, huge pressures will be exerted on the sample upon heating as the graphite and sample attempt to expand against the nearly expansion free quartz. In this method, control of the pressure exerted relies on the ability to shim the sample/graphite combination within the hole in the quartz. Other materials can be used for the expansion-caused pressure fixture, but the selection of quartz and graphite is common due to the materials' cleanliness and the ability of these materials to withstand high temperatures and allow large pressure application.

These methods of applying uniaxial pressure on the samples suffer from difficulty in control of the pressure applied. While the vise or weight methods are more easily reproduced, the attainable pressures are

not as great as the hundreds to thousands of MPa attainable using the thermal expansion method. The major disadvantage of the thermal expansion method, however, is the difficulty in controlling the applied pressure since it is nearly impossible to quantify the amount of pressure being exerted at the annealing temperature for a given arrangement of graphite, sample and shims. The most important difficulty associated with both methods is that of applying the pressure evenly over larger and larger areas as the size of the sample or wafer is increased. Especially in the case of the thermal expansion method, even small inhomogeneities, such as the presence of particles between the shims, lead to inhomogeneous pressure application and bonding failure.

One way to avoid the difficulties associated with thermal expansion mismatch is to use lower temperature bonding procedures. This is the advantage, which makes the use of reactive interlayers or oxides attractive. In order to avoid bonding at high temperature, while still creating a direct covalent bond between the crystals involved, ultra-high vacuum (UHV) systems have been employed. Such ultra-clean environments allow for high temperature heat treatments of the wafers to cause the necessary desorption and release of surface passivating species from the samples. The resulting surfaces, though highly reactive due to the unsatisfied bonding requirements of the surface atoms, are not able to react with anything since the UHV chamber is devoid of material for such reaction. The samples can then be cooled to lower temperatures and brought into contact so that the reactive surfaces can instantaneously form covalent bonds. The lower temperature of bonding results in lower levels of thermal stress as the samples are cooled to room temperature.

This last method of UHV bonding presents the ideal conditions for bonding since the needs for both high temperature surface cleaning and the need for low temperature bonding are satisfied. The disadvantage of this technique is the requirement of an UHV chamber with extremely low background pressures. Such chambers have low throughput due to the times needed for purging and pumping to the necessary vacuum. In general, the use of such vacuum chambers is prohibited in industrial settings where large material volumes need to be processed.

Concerning materials systems where pressure application is not absolutely necessary for the formation of a sufficiently strong bond, no exploration of high isostatic pressure on the bond enhancement has been published. Though the initial application of proposed method is for applications where pressure assisted bonding is necessary, the application of isostatic pressure to these other case would be unique and novel. Processed at high enough pressures and temperatures, transformations of any layers at the bonded interface could be induced. Such transitions would alter the behavior of the bonded materials and could yield much improved material as compared to that produced without the application of hot isostatic pressure during processing.

In a typical wafer bonding process, samples are first cleaned of particle and chemical contamination. Ideally the result of this procedure is a set of flat, smooth wafers having only the presence of surface passivating species on the crystal surfaces. Most often, these surface passivating species are oxides of the wafer materials. In the case of bonding where the desired bond is a direct bond between the materials themselves, the passivating species is usually atomic hydrogen chemically bonded to the wafer surfaces. After being cleaned the wafers are then brought into contact whereupon spontaneous bonding via Van der Waals or Hydrogen bonding mechanisms occurs. Strengthening of the bonding is achieved via heat treatment of the bonded wafers. The materials themselves and the type of bonding needed determine the temperatures and ambients used for this heat treatment. In cases where the desired bond is a direct covalent bond between the wafers, heat treatment is usually in excess of 500°C in an inert gas or H<sub>2</sub> ambient. It is during this step that pressure is often necessitated by the thermal expansion mismatch of the wafers.

The process described here utilizes application of high gas pressure during the high temperature treatment of the preliminary weakly bonded samples and maintaining this pressure on the cooling stage. The Van der Waals weakly bonded samples are loaded into the HIP chamber, followed by chamber purging. The gas used in the chamber is inert but can be varied according to the desired application and necessary purity. Samples are then heated and the chamber is pressurized according to the desired conditions. No mechanical contact with the samples is made as the pressure is applied solely via pressurization of the gas inside the chamber. Temperature levels and ramps can be controlled independently of pressure levels and ramps, making the process fit for tailoring to specific requirements of the materials system involved. Temperature levels ranging from normal to 2000 °C are available as well as pressure levels from vacuum to 2 kbar, depending on the type of processed material. The HIP treatment of the wafers concludes with cooling of the samples to normal temperature under the pressure and subsequent depressurization of the chamber. An example of one configuration of the processing parameters is given below.

After HIP processing the samples are ready for treatment as a single wafer.

Currently, the proposed process has been successfully implemented for the bonding of four different materials systems. These systems are: Si/Si homobonding, InP/InP homobonding, InP/Si heterobonding and Epitaxial InGaAs-on-InP/Si heterobonding. The treatment used preliminary hydrophobically bonded wafers. Such wafers are prepared so as to have Hydrogen terminated surfaces before Van der Waal bonding. The bond formed at room temperature between these wafers is very weak but is sufficient to allow handling of the wafers for loading into the HIP chamber. Most important is that this preliminary weak bonding was enough to prevent penetration of a pressure transmitting media (for example argon gas) into the space between wafers. This allows using direct application of gas pressure to wafers without wafer encapsulation. The specific pressure assisted process consisted of a temperature ramp of 2°C/min to 300°C for a dwell time of 30 minutes before beginning a 10°C/min ramp to 650°C where the temperature was maintained for 65 minutes. The samples were cooled at a rate of about 10°C/min maintaining the constant gas pressure. The pressure was controlled such that no significant pressure was applied until the samples had dwelt at 650°C for 10 minutes. At this time the pressure was then ramped to a final pressure of 200 MPa over the next 45 minutes. The high pressure was maintained for the remaining 10 minutes of 650°C heating and for the whole cooling process.

Upon removal from the chamber, all samples were found to be very strongly bonded together, even those samples where thermal stresses are known to cause bonding failure without the application of pressure. No characterization of the electrical quality of the interface has been made with the exception of the sample having the epitaxially grown InGaAs-on-InP structure bonded to Si. This sample has been successfully processed into a simple photodetector. Unlike samples having this same structure but different bonding processes, these samples showed no etching or delamination anomalies during the device processing steps. Furthermore, the detectors exhibited photo-induced current without any applied voltage. Such behavior was not observed in those detectors previously fabricated at UCSD using standard anvil based bonding techniques.

Applications where thermal expansion mismatch requires some special treatment of the bonded pair in order to ensure successful bonding obviously stand to benefit from this gas pressure assisted method. On application of direct wafer bonding, or fusion, is currently being pursued at the commercial level. This application is the Si/InGaAs Avalanche Photodiode (APD), which requires a high quality bonded interface between materials having different thermal expansion coefficients. Other possible applications include solar cells utilizing wafer fused junctions between Si, Ge and InP or other III/V-based semiconductors. Such a device would require the transport of charged carriers across the bonded interface in such a manner as is not available using bonding techniques which include some sort of interlayer. One possible applications which are just surfacing in the research literature are those of the wafer fused Heterojunction Bipolar Transistor (HBT) and III/V-on-insulator applications. Such devices as a AlGaAs-GaAs-GaN HBT would allow for very wide bandgap materials to be integrated with materials to which the formation of the p-contact is not so difficult as in the case of the wide bandgap materials.

Since the application of this gas pressure assisted process to wafer bonding is yet very new, its applicability to materials combinations not requiring special treatment for successful bonding is not clear. However, further research into the effects of high pressure bonding on samples where amorphous interlayers are seen to form, or where defect formation at the interface occurs, may reveal the opportunity for significant impact on a wider range of wafer bonding applications.